

# PATENT SPECIFICATION

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## DRAWINGS ATTACHED

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## (54) IMPROVEMENTS IN OR RELATING TO VISUAL DISPLAY APPARATUS

(71) We, WESTERN ELECTRIC COMPANY, INCORPORATED of 195 Broadway, New York City, New York State, United States of America, a Corporation organized and existing under the laws of the State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to visual display apparatus.

Interest in laser display systems is based on the premise of screens of essentially unlimited size. Many of the elements necessary for such systems are presently available. High intensity lasers operating at a variety of frequencies within the visible spectrum have been demonstrated as having modulation and scanning techniques of sufficient capacity for most projected uses.

One popular approach, production of images by direct reflection of visible emission is subject to two drawbacks. First, images are monochromatic of a particular well-defined wavelength so that images produced by use of an argon-ion laser, for example, may be blue and black; and, second, reflection of coherent laser output produces a speckled image due to periodic reinforcement of the scattered beam. See Vol. 46, *Bell System Technical Journal*, p. 1479, September, 1967.

So far as is known, there has been no proposal to eliminate speckle from laser visual display systems.

According to one aspect of the present invention there is provided visual display apparatus comprising a laser for emitting a beam of radiation at a wavelength between 0.3 and 0.53 $\mu$ , means for deflecting said beam, a screen, comprising a phosphorescent material,

for receiving said beam and over which said beam is deflected by said deflecting means, and means for modulating the laser output beam to vary the intensity of the emission from the screen, said screen comprising essentially a material which may be represented by the formula



in which  $\alpha$  is yttrium, lutecium or lanthanum or a mixture thereof,  $\beta$  is aluminium or a mixture of aluminium and indium or aluminium and scandium,  $x$  is from 0.001 to 0.15,  $y$  is from 0 to 2.999 and  $z$  is from 0 to 3.0, the display resulting from said deflected laser beam and the emission from said phosphorescent composition being essentially free from speckle.

According to another aspect of the invention there is provided visual display apparatus comprising a laser for emitting a beam of radiation at a wavelength between 0.3 and 0.53 $\mu$ , means for deflecting said beam, a screen for receiving said beam and over which said beam is deflected by said deflecting means, and means for modulating the laser output beam so as to vary the intensity of the emission from the screen, said screen comprising a layer of phosphorescent composition consisting of at least one organic colorant such that the display resulting from said deflected laser beam and the emission from said phosphorescent composition is essentially free from speckle.

In one embodiment of the invention there is used a phosphorescent screen of cerium-activated garnet energized by a laser emitting in the visible spectrum at a somewhat shorter wavelength than the bulk of the emission from the screen. In a preferred arrangement yttrium aluminium garnet containing cerium is used. The characteristically yellowish cast of the

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emission from this phosphor as seen by the eye is adjusted to appear more nearly white by deliberate reflection of a portion of the laser emission.

5 From the compositional standpoint, a preferred form of this embodiment of the invention utilizes a screen coated with cerium-doped yttrium aluminium garnet (YAG) energized by an argon-ion laser arranged so as to emit at 4880 Å. The cerium-activated phosphor emits over a broad range of wavelengths centering about 5500 Å.

10 Variations include other laser sources, such as a cadmium-ion laser which may emit at 4416 Å, as well as variations in the phosphor composition. The absorption peak for the phosphor may, however, be shifted to more closely match a particular energizing source; and to this end, in the garnet, aluminium may be partially replaced by gallium to shift the absorption to shorter wave-length, or yttrium may be replaced, in whole or in part, by gadolinium to shift the absorption to longer wavelength. Since a shift in absorption generally produces a corresponding shift in emission in the same direction, colour adjustment (for example, to produce a white image) by reflection of a portion of the laser beam continues to be feasible.

15 When the phosphor composition is at least in part organic due to the large variation of materials which are suitable for use, few limitations are placed on the nature of the energizing laser. Suitable lasers include argon-ion emitting at 4880 Å and cadmium-ion emitting at 4416 Å. The range of suitable exciting wave-lengths for usable monochromatic displays is from about 2500 Å to about 5500 Å.

20 Specific wavelengths within this broad range are chosen in accordance with the phosphor characteristics. Generally speaking, suitable phosphor materials are organic dyes or pigments many of which are commercially available and in widespread use.

25 In this description, use will be made of the term "colourant" or "organic colourant". It is to be understood that this term includes photoluminescent organic dyes and pigments. Pigments are particularly useful and may be formed by dissolving a dye in an organic resin solution which is subsequently condensed. It is known that luminescent efficiency in certain cases may be enhanced if the dye is absorbed on a colloid which may take the form of gel fibres or particles of high molecular weight polymers.

30 As in the YAG-cerium phosphor display, absorptions in the phosphor are generally broadband and the emission peak is relatively insensitive to a shift in energizing wavelength. This phenomenon is quite useful since it may permit substitution of laser sources without marked change in apparent emission colour.

35 Monochromatic displays result from use of homogeneous phosphor screens. These may be

present as self-supporting members or as coatings, and they may be made up on one or any combination of colourants required to produce the desired balance. Similarly, the amount of reflected laser radiation may be varied by deliberate inclusion of "inert" ingredients in the phosphor. So, for example, a filler such as talc results in an increase in ratio of reflected to converted energy.

40 For a better understanding of the invention, reference is made to the accompanying drawings in which:—

FIG. 1 is a perspective view of a system embodying the invention;

FIG. 2 on co-ordinates of relative intensity based on a maximum scale value of 100, and wavelength in microns, is a plot of the emission and associated excitation spectra for unmodified cerium-doped YAG;

FIG. 3 on co-ordinates of intensity in arbitrary units and wavelengths in angstroms, is a plot of the emission for illustrative colourants under 4880 Å excitation; and

FIG. 4 is a chromaticity diagram showing the co-ordinates of several particularly useful phosphor emissions.

FIG. 1 is a perspective view of a simple system embodying the invention. Energizing light is produced by laser 10 which may, for example, be an argon-ion laser or a cadmium-ion laser. The emerging beam 11 first enters modulator 12 which is provided with a modulating signal by means, not shown, for amplitude modulating the beam. Modulation may be accomplished, for example, by electro-optic, acousto-optic or magneto-optic techniques.

FIG. 2 presents the emission and related excitation spectra for cerium-doped YAG. The emission spectrum is in broken outline with a broad peak having its maximum value at a wavelength of about 0.55 micron. The associated excitation spectrum shown in solid outline is a measure of the intensity of the emission noted for various pump frequencies. The most pronounced excitation peak coincides with a pump wavelength of about 0.46 micron. The emission wavelengths for two prominent laser lines are also indicated. The first, for the argon-ion laser, is at 0.488 micron. The second, for the cadmium-ion laser, is at 0.4416 micron. The laser lines are shown as solid vertical lines.

A description of suitable acousto-optic devices is contained in Vol. 46, Bell System Technical Journal p. 367, February, 1967. Suitable electro-optic devices are described in Vol. 38, *Journal of Applied Physics*, pp. 1611—1617, March, 1967. In any event, modulation may be accomplished by altering the total amount of light of a particular polarization sense which is passed by an analyser incorporated in the modulator, or alternatively by controlling the amount of light which is deflected acousto-optically.

Upon emerging from modulator 12, the beam, now denoted 13, enters deflector 14 which produces the appropriate horizontal and vertical deflection so as to fill screen 15. Deflector 14 may advantageously operate on an acousto-optic principle, see, for example, Vol. 57 Proceedings of the *IEEE* p. 160, February, 1969. The deflector 14 may also perform the modulation function eliminating the need for a separate modulator 12. Earlier deflector systems utilize mechanical, sometimes motor driven, scanners.

One suitable composition for the phosphor screen contains trivalent cerium in an appropriate host. Emission of  $Ce^{3+}$  is generally in the near ultraviolet portion of the spectrum. However, it is known, probably due to the large crystal field splittings in garnet such as YAG, that emission may be shifted to the visible portion of the spectrum. As seen from FIG. 2 the emission for YAG:  $Ce^{3+}$  is quite broad with a peak at about 0.55 micron (yellowish white). The peak absorption in that lattice centres about 0.46 micron and this absorption spectrum is suitable for use either with the argon ( $4884\mu$ ) or cadmium ( $4416\mu$ ) laser. As discussed in a subsequent section, there may be no particular advantage gained by shifting the absorption to exactly coincide with the laser emission.

While reference has been made to "absorption spectrum", only the absorbed energy which is converted to visible emission as discussed, is of consequence. Absorbed energy usefully converted in this fashion may be represented in terms of an "excitation" spectrum, and it is in these terms that the data of FIG. 2 is represented.

The excitation spectrum in the cerium-doped garnet may be shifted to accommodate the lasers discussed or to more effectively utilize other laser sources. To this end, the prototypical composition,  $Y_3Al_5O_{12}$ , may be modified by partial or total substitution of gallium for aluminium and/or gadolinium for yttrium. The former has the effect of moving the excitation peak to shorter wavelength while the latter has the opposite effect. The peak of the excitation spectrum may be tailored in this manner within the range of from about .33 micron to about .48 micron; however, useful excitation may be accomplished over the broader range of about 0.30 micron to 0.53 micron.

A shift in the excitation spectrum produces an accompanying shift in the emission spectrum with the range of emission peaks being from about 0.51 micron to about 0.61 microns. For the preferred embodiment designed to produce a white or near-white image, the emission peak should not be at wavelengths less than about .52 micron (corresponding with an excitation peak of about .43 micron which results in a YAG composition modified by substitution of about 45 atom per cent. gal-

lium for aluminium). From the same standpoint for this preferred embodiment, the phosphor should not be modified so as to result in an excitation peak at wavelengths greater than about  $0.58\mu$  (or, more properly energization should not exceed this limit) since even ineffective conversion will result in addition of some longer wavelength light and, therefore, will impart a yellowish tinge to the reflected emission, YAG in which 70 atom per cent. yttrium is replaced by gadolinium corresponds with this condition and, therefore, this represents the maximum uncompensated partial substitution of gadolinium for the preferred embodiment.

Suitable phosphor compositions depend upon cerium activation. A suitable cerium range is from about .001 to about .15 atom per formula unit of garnet (based on the stoichiometry  $Y_3Al_5O_{12}$ ). ( $Ce^{3+}$  substitutes for yttrium and therefore reduces the amount of this component by an equal amount). The lower limit on cerium content represents the minimum concentration resulting in a readily discernible re-emission image, while the maximum approximately coincides with the solubility limit in the garnet. A preferred cerium range is from .005 to .10. The lower limit is based on minimum concentration required for a re-emission image discernible in ordinary room lighting, and the upper limit is occasioned by the fact that further increase results in little improvement. Its preference is based largely on economics (as compared with the broad maximum above).

In view of the above considerations, the overall garnet phosphor limits may be set forth as:



in which

x is from 0.001 to 0.15 or in the preferred range is from 0.005 to 0.10,  
y is from 0. to 2.999 and  
z is from 0. to 3.0.

Certain other substitutions are possible. So, for example, lutecium or lanthanum may be substituted for yttrium, and indium or scandium may replace aluminium in part. However, since suitable excitation and emission spectra may be obtained in the more common and more economical YAG or substituted YAG system, it is not expected that further modifications will go into commercial use.

While occasions may arise in which it is desired to produce coloured or off-white images, the embodiment is primarily concerned with white or near-white images. In the unmodified YAG:Ce system using an argon or cadmium laser, white images may result by compensation of the secondary yellow cast emission by some reflection of the shorter wavelength laser emission. Under these

circumstances it is desired to design layer thicknesses and compositions or provide for some reflection such that total absorption does not result.

- 5 Modification of the YAG:Ce system within the compositional range described may shift the emission so that it needs no compensation. This may be accomplished for example, by partial substitution of gallium for aluminium in the 20% to 60% range per formula unit. Under such circumstances, the phosphor layer is designed so as to result in little or no reflection. This may be accomplished by providing for essentially complete absorption and minimal reflection.

- 10 In one experimental arrangement, apparently white images resulted from use of the composition  $Y_{1.19}Ce_{0.81}Al_2O_{12}$ . It was found that approximately 50% of the energy of a one watt 488 $\mu$  argon beam was absorbed in a layer thickness of about 0.4 millimetres. The image could be further intensified by providing a mirror backing thereby resulting in total absorption (within the excitation band) of about 75% of the laser energy. The approximate 25% of the laser energy which is reflected suffices to compensate for the yellowish cast of the re-emission.

- 15 FIG. 3 presents the emission spectra for two organic phosphors and their 50—50 blend. The phosphors are 4-amino, 1,8-naphthal p-xylylimide (peaking at 5300 Å) (curve A) and Rhodamine (peaking at 6050 Å) (curve B). Both fluoresce with high efficiencies (greater than 50%) under 4880 Å excitation. The broken line represents a particulate 50—50 mixture of these two phosphors. The individual phosphors fluoresce yellow-green and red. Their combined output is orange. The blue content of radiation from the screen can also be enhanced by addition of reflective matter to increase the fraction of 4880 Å laser radiation reflected when this argon-ion laser radiation is used, for example. Hence, the overall effect is to produce a white appearance to the eye.

- 20 FIG. 4 is the internationally accepted CIE chromaticity diagram (see *Applied Optics: A guide to Modern Optical System Design* (J. Wiley & Sons 1968) Ch. 1 by L. Levi) which can be used as a guide in assessing the colour quality of a display system. In this diagram, the saturated (monochromatic) colours are located on the perimeter of the horse-shoe-shaped plot, while colours of decreasing saturation approach illuminant C which is a white colour equivalent to average daylight illumination. Every real colour, regardless of its spectral complexity, can be represented by a single point on or within this plot. A straight line connecting any two points (primaries) represents the locus of possible colours that can be achieved by blending them in varying proportions. Similarly, the gamut of colours possible by the combination of more than two primaries

are those which fall within the polygon determined by straight lines which connect adjacent primaries. As an example, the dotted triangle in FIG. 4 encloses the colour gamut of a shadow mask colour CRT. For comparison, there is also shown the major cadmium and argon laser lines at 4416 Å, 4880 Å, and 5145 Å as well as the emissions of three phosphors (Nos. 3485, 3483 and 3484) which are Rhodamine based pigments). The arrow on the 3485 dye emission shows the effect of adding phthalocyanine toner, which selectively absorbs the longer wavelength yellow and red portion of the emission to produce a more vivid green. It can be seen that the combination of light from either of these blue laser sources and emission from the 3483 and 3485 phosphors results in a colour gamut similar to that of the colour cathode ray tube.

A black and white display can be achieved by scanning a monochromatic laser beam on a viewing screen that is coated with an appropriate blend of phosphors and direct scattering materials such as powdered MgO or talc. For example, a combination of scattered light from a blue argon-ion laser beam (4880 Å) and blue-to-red converted light from either of the Rhodamine dye phosphors 3483 and 3484 can produce a white appearance since a straight line connecting these primaries on the chromaticity diagram passes very near to illuminant C.

A combination of more than two primaries can also be used to produce white. As an example, a Cd-He laser beam which illuminates a correctly proportioned mixture of MgO and dye phosphors 3484 and 3485 can be used to achieve a white appearance. Alternatively, MgO may be replaced by pyrene-containing materials or 7-diethyl amino, 4-methyl coumarin-containing materials (blue-to-blue and ultraviolet-to-blue converting phosphors, respectively, to completely eliminate speckle.)

Regardless of how many phosphors are used, it is apparent from the chromaticity diagram that a necessary condition for achieving a true white is that the illuminating laser beam have a wavelength of approximately 4950 Å or shorter. Otherwise, it is impossible to include illuminant C within a polygon whose primaries are the source and any combination of longer wavelengths that can be achieved by down-conversion of frequency. Fortunately, the argon-ion laser satisfies this necessary condition. Representative materials and the colour which they fluoresce include pyrene (blue); fluorescein (yellow-green); eosin (yellow); Rhodamine-B (red); Rhodamine-6G (yellow); acridine (blue); acriflavin (yellow-green); naphthalene red (red); auramine-O (yellow-green); 4-amino, 1,8-naphthal p-xylylimide (yellow-green); and 7-diethylamino, 4-methyl coumarin (blue). Other dyes are xanthene, azine, oxazine, thiazine, acridine, flavin,

naphthalimide and coumarin derivatives. Data on absorption and emission of selected dyes is given in Table I. Such data may be used to optimize screen composition for a given laser source.

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TABLE I

Absorption and Fluorescence Bands of Dyes in Aqueous or Alcoholic solutions

(Approximate limits of bands in Å; peaks of bands in parentheses)

Compounds	First Absorption Band	Fluorescence Band	Colour
<b>I. XANTHENE:</b>			
Fluoran	u.v.	2900—4600 (3200)	violet strong
Fluorescein (Dihydroxyfluoran)	4400—5200 (4940)	5100—5900 (5180)	yellow-green very strong
Eosin (Tetrabromofluorescein)	4500—5600 (5170)	5200—6000 (5400)	yellow strong
Erythrosin (Tetraiodofluorescein)	4600—5560 (5165)	5180—5880 (5375)	yellow weak
Rose bengale (Tetraiodo- tetrachlorofluorescein)	(5438)	5500—6700 (6000)	orange very weak
Rhodamine B extra	4800—6000 (5500)	5500—7000 (6050)	red strong
Rhodamine 6 G	4800—5900 (5260)	5360—6020 (5550)	yellow strong
Acridine red	4550—6000	5600—6800	orange medium
Pyronine B	5400—5900	5600—6500	orange medium
<b>II ACRIDINE:</b>			
Acridine	3000—4500	4000—4800	blue-violet medium
Acridine yellow	u.v.—5200	4750—6400	green
Euchrysine	u.v.—5400	5050—6700 (5850)	greenish- yellow medium
Rheonine A	u.v.—5100	4700—6500	green weak
Acriflavine (Trypaflavine)	u.v.—5000	4850—6600	yellowish- green strong

TABLE I (continued)

Compounds	First Absorption Band	Fluorescence	
		Band	Colour
III AZINE:			
Magdala red	4000—6000 (5240)	5500—7000 (6000)	red strong
Safranine	(5390)		yellow-red
IV THIAZINE:			
Thionine	4800—6300 (5800)		orange medium
Methylene blue	5500—7000		red medium

A naphthalimide dye; 4-amino, 1,8-naphthal-p-xenylimide (yellow-green) and two Rhodamine dyes (orange and red) are exemplary. Their emission spectra for 4880 Å excitation exhibit peaks at 5300 Å (yellow-green), 6050 Å (Orange-red) and 6200 Å (red) respectively. It has been determined that their lifetimes are all considerably less than one microsecond and their absorption cross sections are so large that the entire laser beam is absorbed within thin films which are approximately 0.1 mm thick. Their absorption bands are quite broad, including essentially all of the violet and blue and a portion of the green. It has been estimated that their quantum efficiencies are above 50%. Thus, these materials are well suited for laser display systems.

The colours of these fluorescing dyes may be modified somewhat by varying the type of carrier which is used to form pigments, and to a lesser extent by varying the type of vehicle, or binder, into which the pigment is incorporated. It is also possible to modify colours by combining fluorescent dyes with nonfluorescent dyes that selectively absorb a portion of the emission spectrum. For example, the emission spectrum of the naphthalimide dye (type 3485) shown in FIG. 3 peaks at 5300 Å, in the green. Normally this fluorescence appears to have a yellowish-green cast due to the broad tail of the emission spectrum which extends into the yellow and red. However, this tail can be substantially reduced by the addition of a nonfluorescing green toner such as a phthalocyanine which absorbs in the yellow and red. The result then is a trade-off of brightness for the ability to limit the spectral content.

In contrast to the many yellow and red emitting dyes, blue emitting dyes are less common. However, examination of pyrene in dilute alcoholic solutions indicates that it is blue-fluorescing when excited by short wave-

length blue light such as the 4579 Å emission of an argon laser or the 4416 Å emission of a cadmium laser, while it becomes green fluorescing under longer wavelength blue excitation such as the 4880 Å line of an argon laser. In addition, pigments of coumarin which fluoresce blue under near ultraviolet excitation are commercially available.

In the system having an organic colourant phosphor and using an argon or cadmium laser, white images may result by adjustment of the screen composition to a yellow cast so that reflected blue adds in to give a whiter image.

However, as with the garnet phosphors, suitable choices of phosphors can readily be made so that no compensation is needed. This may be accomplished, for example, by blending particulate mixtures of blue, yellow and red emitting phosphors. Under such circumstances, the phosphor layer is designed so as to result in little or no reflection. This may be accomplished by providing for essentially complete absorption and minimal reflection.

It is apparent that final design of a phosphor screen depends upon power levels, laser wavelengths, phosphor absorption level, and emission wavelength. Reflection of unconverted laser emission may be enhanced by using thin coatings, by reflective backings (although this also results in additional secondary emission during retraversal) and by incorporation of "inert" reflective material such as talc.

Variation may utilize a laser source which is behind rather than in front of a screen and a variety of other arrangements for folding beams, for modulation, and for deflection of the beams.

#### WHAT WE CLAIM IS:—

1. Visual display apparatus comprising a laser for emitting a beam of radiation at a wavelength between 0.3 and 0.53 $\mu$ , means for deflecting said beam, a screen, comprising a

- phosphorescent material, for receiving said beam and over which said beam is deflected by said deflecting means, and means for modulating the laser output beam to vary the intensity of the emission from the screen, said screen comprising essentially a material which may be represented by the formula



- in which  $\alpha$  is yttrium, lutecium or lanthanum or a mixture thereof,  $\beta$  is aluminium or a mixture of aluminium and indium or aluminium and scandium,  $x$  is from 0.001 to 0.15,  $y$  is from 0 to 2.999 and  $z$  is from 0 to 3.0, the display resulting from said deflected laser beam and the emission from said phosphorescent composition being essentially free from speckle.

2. Apparatus according to claim 1, in which said phosphorescent composition is represented by the formula



3. Visual display apparatus comprising a laser for emitting a beam of radiation at a wavelength between 0.3 and 0.53 $\mu$ , means for deflecting said beam, a screen for receiving said beam and over which said beam is deflected by said deflecting means, and means for modulating the laser output beam so as to vary the intensity of the emission from the screen, said screen comprising a layer of phosphorescent composition consisting of at least one organic colorant such that the display resulting from said deflected laser beam and the emission from said phosphorescent composition is essentially free from speckle.

4. Apparatus according to claim 3, in which said colorant is a derivative of coumarin, xanthene, acridine, Rhodamine, naphthalimide, azine, or thiazine.

5. Apparatus according to claim 3, in which said composition comprises at least one of pyrene, 7-diethylamine 4-methyl coumarin, Rhodamine B, Rhodamine 6G, acridine and 4-amino 1,8-naphthal p-xenylimide.

6. Apparatus according to anyone of the preceding claims in which said laser is an argon-ion laser.

7. Apparatus according to any one of the preceding claims in which said laser is a cadmium-ion laser.

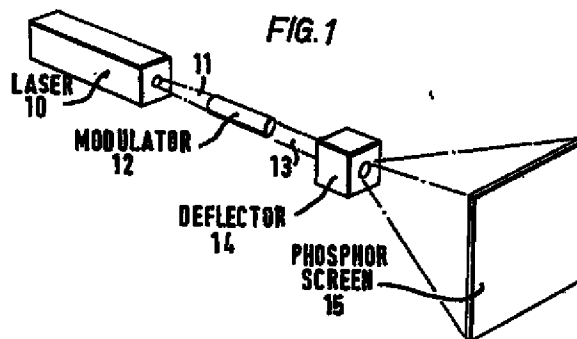
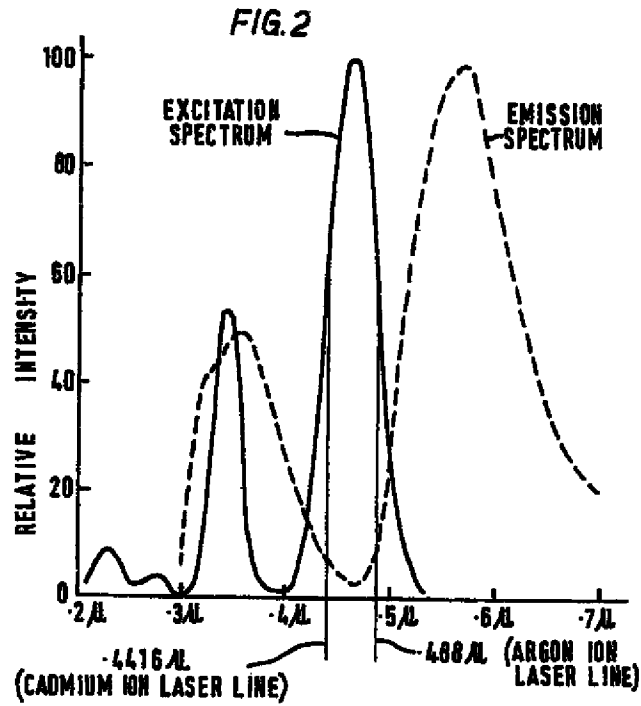
8. Apparatus according to any one of the preceding claims, in which said screen is such that a portion of said radiation beam is unconverted so that the combination of reflected laser emission and the phosphorescent emission from the screen appears essentially white.

9. Apparatus according to any one of the preceding claims, in which said modulating means is an electro-optic modulator and said deflecting means is an acousto-optic deflector.

10. Apparatus according to claim 9, in which said modulator and deflector constitute a single unit.

11. Visual display apparatus arranged substantially as herein described with reference to FIG. 1 and having as a layer upon the screen at least one phosphorescent material herein mentioned.

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COMPLETE SPECIFICATION

3 SHEETS

This drawing is a reproduction of  
the Original on a reduced scale

Sheet 2

FIG.3

